

REMARKS

In the Official Action mailed June 16, 2006, the Examiner rejected claims 8-20. The Examiner cited 35 USC § 112 as the basis for this rejection.

Specifically, the Examiner rejected claim 18. The Examiner objected to this claim because, in the Examiner's view, the claim contains a redundant recitation of a klystron device. The Applicant's disagree with the Examiner's rejection. The claim recites a klystron device or a klystrode device. The devices are related, but they are not the same. Both are separately and specifically called out on page 11, lines 15-20 of the specification. As noted in Rees, D., et al., "Characterization of a Klystrode Device as a RF Source for High-Average-Power Accelerators," Proceedings of the 1995 Particle Accelerator Conference, Vol. 3, pp. 1521-1523 (May, 1995) a klystrode is a hybrid of a klystron with gridded tube technology. A copy of this article is attached. In view of this distinction, Applicants submit that the reference to both klystrode and klystron devices in claim 18 is not redundant. The Examiner is respectfully requested to withdraw his rejection of claim 18 under 35 USC § 112.

With regard to claims 8 and 19, the Examiner rejected these claims because they lacked adequate antecedent basis for "the cathode surface" and the "the grid surface." The applicants have amended claims 8 and 19 to include the requisite antecedent for these limitations.

Similarly, the Examiner rejected claim 12 because it lacked the requisite antecedent for "the anode surface." The applicants have amended claim 12 to include the requisite antecedent. In view of these amendments, the applicants

respectfully request the Examiner to withdraw his rejections of claims 8, 10 and 19 in this regard.

The Examiner states that the term "one or more flexural members" renders claims 11, 13 and 14 vague and rejects these claims under 35 USC § 112 on this basis. Specifically, the Examiner queries whether these are the same flexural members referred to in claim 8 or different therefrom. The Examiner is referred to Figures 1A-1C and the accompanying text (Applicants' specification at page 9, line 9 to page 10, line 11) in this regard. There it clearly describes the locking mechanisms as being attached to the substrate by flexural members (e.g., hinges). These flexural members are separate and apart from the flexural members (13) associated with the cathode (12), the flexural members (15) associated with the grid (14) and the flexural members (17) associated with the anode (16). There is also described therein a mask (20) attached to the substrate by hinge mechanism (21). Thus, the flexural members for the locking mechanism in claim 11 are clearly different from those recited in claim 8. The flexural members for the additional grids in claim 14 are clearly different from the flexural members associated with one of the grid, cathode or anode in claim 8. However, with regard to claims 9 and 13, which recite flexural members for the cathode and anode, those claims are amended to refer to the flexural members recited in claim 8.

In view of these amendments, the Examiner is respectfully requested to withdraw his rejection of claims 8-20 under 35 USC § 112.

The Examiner rejected claim 8-11, 16, 17 19 and 20 as obvious under 35 USC § 103(a). The Examiner cited US Patent No. 5,536,988 to Zhang (Zhang et al.) as the basis for this rejection. Applicants' invention is directed to microwave

vacuum tube devices and, in particular gridded microwave tube types. The device comprises a substrate, a cathode attached to the substrate, a grid attached to the substrate and an output structure. The cathode and grid are substantially parallel. One or both of the cathode and grid are attached to the device substrate by flexural members. In the operation of the device, a weak microwave signal to be amplified is applied between the grid and the cathode. The signal applied to the grid controls the number of electrons drawn from the cathode. During the positive half of the microwave cycle, more electrons are drawn. During the negative half, fewer electrons are drawn. The modulated beam of electrons passes through the grid and goes to the anode. A small voltage on the grid controls a large amount of current. As this current passes through an external load, it produces a large voltage, and the gridded tube thereby provides gain. See page 10, line 22 to page 11, line 2 of applicants' specification. Thus, in applicants' device, the grid controls electron emission from the cathode. See page 2, lines 1-3 of applicants' specification. The embodiments of applicants' device in which both an anode and cathode are present are inherently three terminal devices (one for the cathode, a second for the anode and a third for the grid). Applicants' device is easily extended to more than three terminals (by using multiple grids).

Zhang et al. is directed to a process for making field emission devices. Although Zhang et al. describes a device having both a grid and a cathode attached to a substrate, Zhang et al. does not describe a device in which the grid modulates the electrons drawn from the cathode. The grid (282) in Zhang et al. is merely described as a support structure and not described as having a modulating function.

In their previous replies, applicants observed a fundamental distinction between their invention and the Zhang et al. device. Specifically, the applicants observed that Zhang et al. does not describe a control grid. The Examiner agrees with applicants that Zhang et al. does not explicitly disclose a control grid. However, the Examiner states the providing an emission control grid would have been obvious to one skilled in the art based upon the Zhang et al. disclosure. However, the Examiner has failed to identify anything in Zhang et al. that provides any teaching, suggestion or motivation for this modification.

Note that, in applicants' invention, the emitters (30) are formed on the cathode (12). The cathode (12) is perpendicular to the grid (14). See Fig. 1C. This is completely different from the structural relationship between the cathode and the emitter described in Zhang et al. Yet the Examiner maintains that it would be obvious for one skilled in the art to modify the structure in Zhang et al. to impart a modulation function to the grid by simply varying the voltage to the grid in Zhang et al. As applicants have repeatedly observed, the grid in Zhang et al. provides a support function for the emitters thereon. There is no teaching, suggestion or motivation in Zhang et al. to operate the grid described therein to control the emission of the electrons disposed thereon in the manner disclosed and claimed by applicants.

Applicants have further emphasized this distinction by amending claims 8 and 19 to recite that the grid is configured to modulate the electrons drawn from the cathode. Support for this amendment is found on page 10, lines 22-26. Applicants submit that merely controlling the amount of voltage to the support grid 282 for the gated field emitters (Col. 11, ll. 29-36 of Zhang et al.), which the Examiner contends is

obvious to one skilled in the art, would not necessarily modulate the electrons drawn from the cathode. It is for this reason that applicants submit that amended claims 8 and 19 are not obvious in view of Zhang et al.

With regard to claims 9-11, 16, 17, and 20, these claims are also patentable over Zhang et al. for the aforesaid reasons by virtue of their dependence on either amended independent claim 8 or amended independent claim 19. Claims 8 and 19 are patentable over Zhang et al. for the previously stated reasons. In addition, with regard to claim 9, the Examiner incorrectly asserts that Zhang et al. describes cathode and grid surfaces substantially perpendicular to the device substrate. The emission surface of the cathode in Zhang et al. is clearly parallel to the substrate, not perpendicular thereto. See emitter tip 304 in FIG. 8(e). In Zhang et al., the emission tip emits in a direction perpendicular to substrate 12. Since the emission tip is clearly perpendicular to the substrate surface, the emission face in Zhang et al. is most clearly in a plane parallel to substrate 12.

In view of the foregoing arguments and amendments, the applicants respectfully request that the Examiner withdraw the rejection under 35 USC § 103(a), of claims 8-11, 16, 17, 19 and 20.

The Examiner also rejected claims 12-14 and 18 as unpatentable under 35 U.S.C. § 103(a). Specifically, the Examiner states that claims 12-14 and 18 are obvious in view of the combination of Zhang et al. in view of Komatsu.

At the outset, applicants note that the Examiner has failed to make a *prima facie* case for obviousness based on this combination of references. Specifically, the Examiner has not

indicated any teaching, suggestion or motivation in the references themselves to combine the teachings of Zhang et al. and Komatsu. Pursuant to MPEP 706.02(j), the Examiner is required to set forth an explanation of the reasons why one of ordinary skill in the art at the time the invention was made would have been motivated to make the proposed modification.

The motivation for the combination put forth by the Examiner certainly does not come from Zhang et al., which does not disclose or suggest adding an additional electrode. Nor does Zhang et al. disclose or suggest any type of device that would require the addition of an anode. Furthermore, Zhang et al. does not mention anything with regard to operating the disclosed device that suggests the addition of another electrode to one skilled in the art. Certainly there is no such suggestion in Komatsu. The Komatsu device is structurally very dissimilar to the Zhang et al. device. For example, contrast the Komatsu emitters (FIG 2F illustrates emission projections 4 from cathode 3) with the cathode emitters 22 in Zhang et al. If it would be obvious to add an anode to the Zhang et al. structure, as the Examiner contends, the applicants query where the placement of such an anode is described or suggested in either reference? Given that there is simply no suggestion, teaching or motivation of this combination in either reference, the applicants respectfully request that the Examiner withdraw his rejection of claims 12-14 and 18 under 35 USC § 103(a) based upon Zhang et al in view of Komatsu.

The Examiner rejected claim 15, stating that the claim is obvious under 35 U.S.C. § 103(a). The Examiner cited Zhang et al. in view of Bower as the basis for his rejection. At the outset, applicants again note that claim 15 depends from claim 8. Claim 8 is not obvious, under 35 USC § 103(a) in view of Zhang et al. for the aforesaid reasons. Therefore, claim 15

is patentable over the cited combination of reference by virtue of its dependence on claim 8.

In view of the foregoing arguments and amendments, applicants submit that claims 8-20 are in condition for allowance.

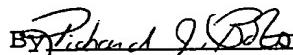
As it is believed that all of the rejections set forth in the Official Action have been fully met, favorable reconsideration and allowance are earnestly solicited.

If, however, for any reason the Examiner does not believe that such action can be taken at this time, it is respectfully requested that he/she telephone applicants' attorney at (908) 654-5000 in order to overcome any additional objections which he might have.

If there are any additional charges in connection with this requested amendment, the Examiner is authorized to charge Deposit Account No. 12-1095 therefor.

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# CHARACTERIZATION OF A KLYSTRODE AS A RF SOURCE FOR HIGH-AVERAGE-POWER ACCELERATORS\*

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## Abstract

The klystrode is a relatively new type [1]–[4] of RF source that has demonstrated dc-to-RF conversion efficiencies in excess of 70% and a control characteristic uniquely different from those for klystron amplifiers. The different control characteristic allows the klystrode to achieve this high conversion efficiency while still providing a control margin for regulation of the accelerator cavity fields. We present test data from a 267-MHz, 250-kW, continuous-wave (CW) klystrode amplifier and contrast this data with conventional klystron performance, emphasizing the strengths and weaknesses of the klystrode technology for accelerator applications. We present test results describing that limitation for the 250-kW, CW klystrode and extrapolate the data to other frequencies. A summary of the operating regime explains the clear advantages of the klystrode technology over the klystron technology.

## I. INTRODUCTION

The klystrode combines attributes from both the gridded-tube and klystron technologies, with an input structure borrowed from gridded-tube technology and a klystron-like output cavity. It is a density-modulated amplifier. Figure 1 is a schematic of the klystrode.

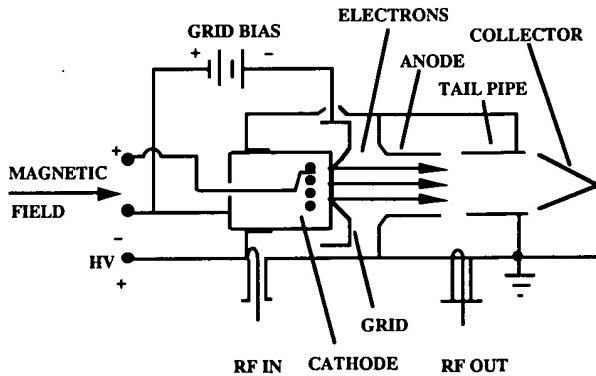


Figure 1: Schematic of the klystrode amplifier tube.

Since the dc acceleration region is separate from the power extraction region in the klystrode, it has transit-time advantages over conventional gridded tubes. Because it is a current-modulated device, the current bunch is more nearly monoenergetic and high efficiencies can be achieved without the stability issues surrounding high-efficiency klystrons. The primary klystrode market is UHF television transmission,

where the klystrode provides up to 60 kW of peak power. Two high-power klystrode developments promise the extension of TV technology to power levels that are of interest to the particle accelerator community. The first development produced a pulsed klystrode at 425 MHz, which achieved in excess of 750 kW peak at a 10% duty factor [1]. The klystrode gain was in excess of 20 dB, and an efficiency greater than 70% was demonstrated. The second high-power klystrode development provided a 250-kW continuous-wave (CW) klystrode at 267 MHz and is the basis for the information presented in this paper [4]. This klystrode was originally developed by Varian for the Chalk River Nuclear Laboratories of Atomic Energy of Canada Limited as a power source for a radio frequency quadrupole accelerating cavity [5]. The program has since moved to Los Alamos National Laboratory, where the system is being used as a test stand for advanced accelerator applications [6]. Our interest in high-power klystrodes is motivated by their high efficiency and their control characteristic. All high-power klystrode developments have achieved an efficiency in excess of 70%, which is better than that for klystrons currently in accelerator service; and unlike the klystron, it is possible to modulate the input signal to the klystrode and vary the output while still achieving high efficiency.

In accelerator service, the high-power amplifier is part of a fast control loop, which maintains the accelerating cavity field amplitude and phase at a desired set point. The klystron provides its maximum efficiency only at saturation, where the power transfer curve is essentially flat, making control by amplitude modulation of the drive signal impossible. In order to exercise control over the cavity field, we must typically operate the klystron with a control margin (the amount of operation below saturation) of 10% to 20%. A 20% control margin decreases the efficiency of a klystron operating at 70% efficiency at saturation to 56% at the nominal operating point. In contrast, we demonstrate that the klystrode can provide a relatively constant, high efficiency over the last 30% of its power capability.

One advantage of the klystron over the klystrode is its high gain. In many klystron-based accelerator RF systems a small solid-state amplifier drives a klystron with 45–55 dB of gain. The klystrode gain of 20–22 dB increases transmitter complexity and requires an intermediate amplification stage for high-power applications; however, the klystrode does not require a modulator, as does a klystron, for pulsed service because it is configured as a class B amplifier. When large CW accelerators lose their vacuum, they are often pulse-conditioned, and with klystrons expensive modulators are sometimes built solely for conditioning. Such modulators are not required for the klystrode. Klystrons also have demonstrated much higher peak and average power capabilities than have klystrodes.

As an additional advantage of klystron technology, the drive signal is applied to a modulating gap that is not collocated with the cathode surface as is true with the

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klystrode. A portion of the klystrode drive power is dissipated on the cathode surface, providing an additional source of cathode heating. Because of the relatively low gain, this characteristic may ultimately limit the average power capability of the klystrode without additional technology advances in the input structure or cathode material.

## II. EXPERIMENTAL RESULTS

Data representing the klystrode's linearity, phase variation with output power, efficiency variation with output power, and bandwidth is presented in Figures 2–5. The data was taken at 267 MHz. We integrated power meters, a swept-frequency source, and sampled values of beam current and voltage into a LabVIEW-controlled automated test to generate the power transfer, bandwidth, and efficiency plots. We used a network analyzer to measure the phase variation with input power, which we then converted to a plot of phase variation with output power by using the power transfer characteristic. The klystrode transmitter is a three-stage transmitter with the 250-kW klystrode as the final stage. The data presented here are only for the final klystrode stage. The curves in Figures 2 and 3 illustrate the klystrode power-transfer curve and phase response. Figure 4 shows the klystrode efficiency as a function of output power. Figure 5 illustrates the klystrode bandwidth. Inspection of Figure 4 shows that the klystrode provides almost constant efficiency from 180 to 250 kW. Inspection of Figure 2 shows that the power-transfer characteristic is relatively linear in this region. Taken together, Figures 2 and 4 support the earlier assertion that the strength of the klystrode for accelerator service is its capability to provide simultaneously high efficiency and a control margin for regulating accelerator cavity fields.

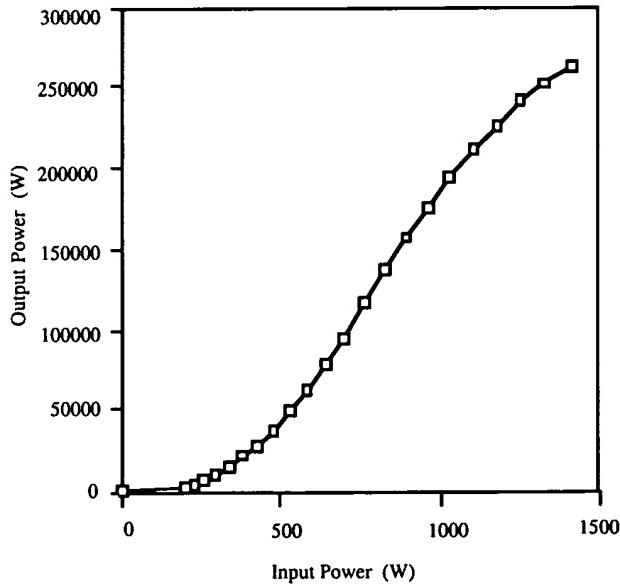


Figure 2: Klystrode power transfer characteristic.

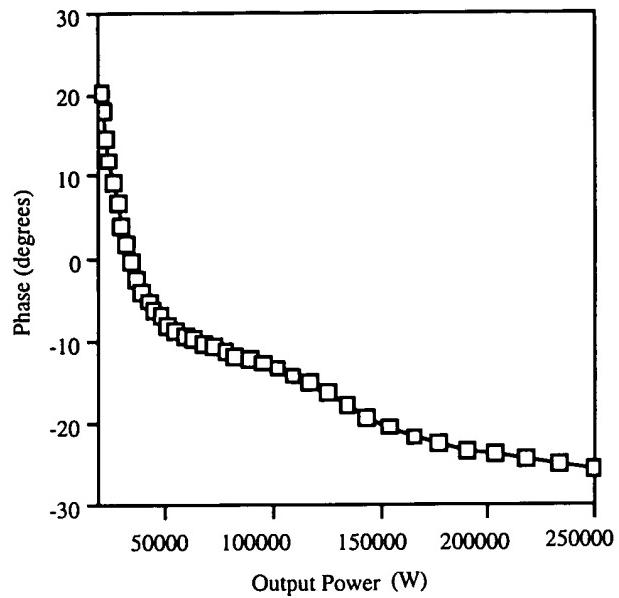


Figure 3: Klystrode phase response.

Figure 6 illustrates the output power versus filament power for the 250-kW klystrode at three nominal output power levels. Tests were performed at nominal output powers of 60 kW, 180 kW, and 234 kW over the filament power range of 175 to 300 W. The filament power was controlled by varying the filament current. The klystrode operates at a nominal value of filament power slightly larger than 250 W (the third data point on each curve).

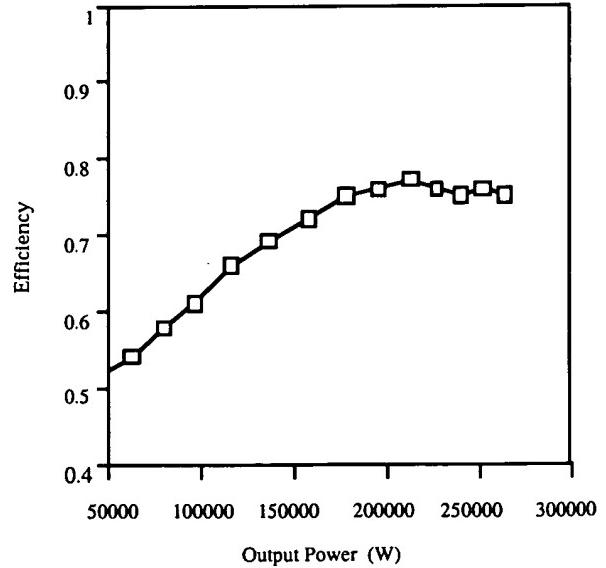


Figure 4: Klystrode efficiency as a function of output power level.

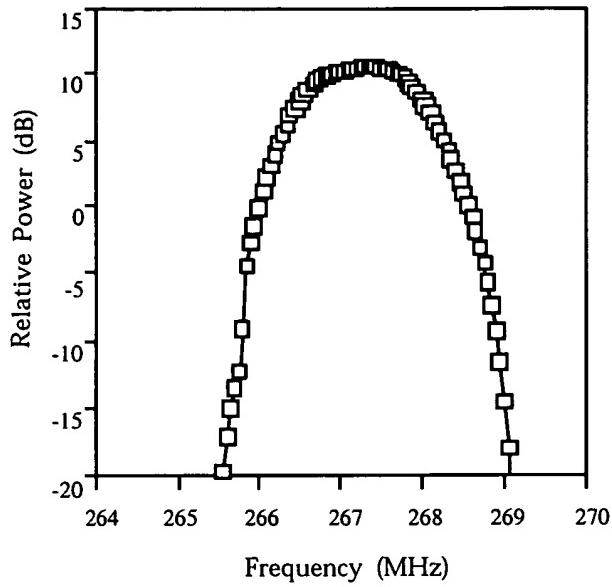


Figure 5: Klystrode bandwidth.

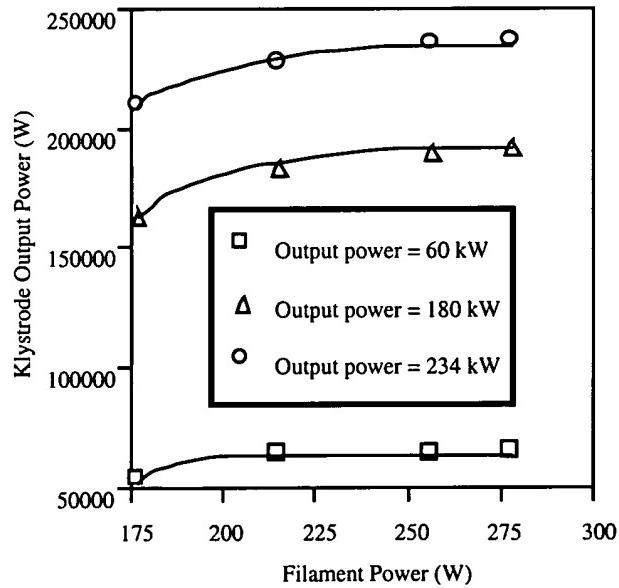


Figure 6: Klystrode output power vs. filament power for three output power levels.

The test results in Figure 6 were intended to quantify the level of filament heating. Inspection of the 180-kW and 234-kW curves shows that the knee is at approximately the same filament power level even though the beam current is different by 30%. This could lead to the conclusion that an appreciable amount of cathode heating is taking place, but more tests are necessary to further quantify this effect.

### III. CONCLUSION

Because of its high efficiency, the variation of its efficiency with output power, and its linearity, we have demonstrated the klystrode to have performance

characteristics that are very appealing for accelerator RF systems. The relatively constant efficiency over a broad range of output power provides a control margin for accelerating cavity fields without the efficiency penalty that must be suffered with klystron amplifiers. The smoothly varying, monotonic phase characteristic of the klystrode is easily controllable, and the magnitude of the phase variation provides abundant phase margin for the other components of the system that contribute to phase variation (capacitor bank droop, beam effects, etc.). We believe that the klystrode has proved its viability as a high-power source at frequencies less than 300 MHz for output powers up to 250 kW CW. It is extremely attractive for CW service because of its high operating efficiency. The klystrode also appears to be a very attractive candidate for low-frequency superconducting accelerator applications that require reduced power levels.

At frequencies in excess of 1 GHz or for high-power, short-pulse service (>500 kW, <10% duty factor) where efficiency is not an issue, we believe the klystron to be the RF tube of choice. Its high gain and proven reliability will reduce total costs. It also tends to be higher perveance than the klystrode, decreasing high-voltage power supply cost.

We are concerned that at higher average power levels, the klystrode technology does not have an appreciable operating history on which to base reliability estimates. We have approximately 664 high-voltage hours on the 250-kW CW klystrode at Los Alamos, and we have had to process the grid at least three times to remove material deposited on the grid by the cathode. We are afraid that the cathode is being overheated by the RF drive power and that the result will be a reduced tube life.

### IV. REFERENCES

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- [6] M. Lynch, D. Keffeler, D. Rees, W. Roybal, "Installation and test results of a high-power, CW klystrode amplifier at Los Alamos National Laboratory," *Proceedings of the 1994 International Linac Conference*, vol. 1, p. 451.